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# ANALYSIS OF SERUM AND WHOLE BLOOD VALUES IN RELATION TO HELMINTH AND ECTOPARASITE INFECTIONS OF FERAL PIGS IN TEXAS

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ABSTRACT: In the summers of 1996 and 1997, 60 wild pigs (*Sus scrofa*) were necropsied from three sites in south Texas (USA) to test the hypothesis that serum and whole blood parameters vary significantly ($P \leq 0.05$) with the prevalence and intensity of parasites infecting wild pigs. We found ten parasite species: five nematodes (*Metastrongylus salmi, Metastrongylus pudentotectus, Stephanurus dentatus, Oesophagostomum dentatum,* and *Physocephalus sexalatus*); four ixodid ticks (*Amblyomma cajennense, Amblyomma maculatum, Amblyomma americanum,* and *Dermacentor variabilis*); and one trematode (*Fascioloides magna*). Among juvenile pigs, the intensity of the four species of ticks, collectively, was negatively correlated ($P \leq 0.05$) with whole blood principal component number one (PC-1); this factor was positively associated with lymphocytes and eosinophils. Lungworm intensity (*Metastrongylus* spp.) among adult pigs was negatively correlated ($P \leq 0.05$) with whole blood PC-2; this factor was negatively associated with segmented neutrophils and monocytes. There were no significant correlations found between parasite prevalences and either serum or whole blood principal component factors. The correlations observed between parasite intensities and serum and whole blood parameters generally were weak. Thus, we found no strong evidence that serum and whole blood parameters provided good predictive information on parasite infections in wild pigs for most practical management decisions.

*Key words:* Blood cells, blood serum, helminths, physiological ecology, pigs, *Sus scrofa,* ticks.

## INTRODUCTION

The feral pig (*Sus scrofa*) is an exotic species inhabiting the southeastern United States, as well as Texas, California, and Hawaii (USA) (Corn et al., 1986). There have been several surveys on wild pig parasites (Coombs and Springer, 1974; Foreyt et al., 1975; Prestwood et al., 1975; Smith et al., 1982; Greiner et al., 1984; Pence et al., 1988), but only a few studies on wild pig blood biochemistry (Williamson and Pelton, 1975; Wolkers et al., 1993, 1994b). Except for some information on packed cell volume (PCV) and hemoglobin concentration (HB), there are no known values reported for whole blood parameters from feral pigs.

In many cases, it would be of great assistance for managers to find dependable methods for predicting parasite presence that did not require killing the hosts. As blood parameters are more thoroughly established, they may have promise as predictors of parasite infections. Physiologic parameters have been studied extensively as a means of evaluating animal health. Among mule deer (*Odocoileus hemionus*), Saltz et al. (1992) found that urine cortisol : creatinine ratios increased throughout the winter in high-density pastures while survival of mule deer yearlings decreased at the same time; low density pastures were characterized by a mild decline in survival throughout the winter. Corn and Warren (1985) found that the urinary urea : creatinine ratio in collared peccaries (*Tayassu tajacu*) reflected nutritional status. A high ratio was correlated with a low digestible energy and high-crude-protein diet. Franzmann and LeResche (1978) found that PCV, HB, calcium, and phosphorus increased with improved health in moose (*Alces alces*). Similarly, Wolkers et al. (1993) found that PCV, HB, and alkaline phosphatase (AP) were positively correlated with bone marrow fat among feral pigs. They proposed that these blood values might be indicators of nutritional status in pigs. In a controlled experiment, Wolkers et al. (1994b) later found that

PCV and HB values of juvenile pigs decreased only in late stages of undernutrition, whereas AP had a progressive decrease throughout food restriction periods.

Although there is evidence that serum and whole blood variables are correlated to measures of health and nutritional status, few researchers have extended these analyses to assessment of parasite infections. Wolkers et al. (1994a) evaluated the possible relationship between parasite burdens and blood and serum parameters in feral pigs and found negative correlations between bone marrow fat and stomach worms (*Physocephalus sexalatus* and *Ascarops strongylina*), as well as between HB and lungworms (*Metastrongylus* spp.). In contrast, serum urea concentration was positively correlated with stomach worms. They did not explore the relationship between bone marrow fat, HB, and serum urea and other parasites, such as liver flukes (*Fascioloides magna*) and kidney worms (*Stephanurus dentatus*). Among other host species, Kuttler and Marble (1960) found that domestic lambs with heavy *Haemonchus* spp. infections had significantly lower levels of albumin, total protein, and PCV than did nonparasitized controls. In contrast, globulin levels were markedly increased in parasitized lambs (Kuttler and Marble, 1960). Woolf et al. (1973) obtained similar results for bighorn sheep (*Ovis canadensis*) with chronic pneumonia, a disease often associated with lungworms (*Protostrongylus* spp.). Diseased bighorn sheep had lower levels of albumin and higher levels of globulins; in addition, the mean white blood cell (WBC) count of sick sheep was significantly higher than that of healthy sheep.

Our objective was to determine whether biochemical and hematologic parameters in the serum and whole blood varied significantly with the prevalence of helminths and ectoparasites found among feral pigs. We tested the null hypothesis that these biochemical values would not vary significantly with either the prevalence or intensity of parasites in wild pigs.

## METHODS

This study was conducted in south Texas at three sites during the summers of 1996 and 1997. The Welder Wildlife Foundation (WWF) (28°20′N, 98°50′W) is located 16 km north of Sinton in San Patricio County; the King Ranch (27°31′N, 97°52′W) occurs at Kingsville in Kleberg County, and the Chaparosa Ranch (28°42′N, 100°30′W) is located in Zavala County 64 km east of Eagle Pass, Texas.

Traps were baited with fermented corn, prepared by soaking cracked corn in a 120-liter garbage can filled with water (Shender, 1998). All trapping and handling procedures were conducted in accordance with the Humboldt State University, Arcata, California, Institutional Animal Care and Use Committee Section 5 protocol (Number 95-96.W.17). The meat, skulls, and skeletal materials of each pig were donated to various charities and educational institutions after the essential samples were collected (Shender, 1998).

Trap design varied with site. At Chaparosa Ranch, we used box traps (3 m × 1.5 m × 1.5 m), with a guillotine-style drop gate door triggered by a rope in the rear of the trap. At WWF we used square panel traps (2 m × 2 m × 2 m), which included a roof to prevent pigs from escaping. The anterior wall had a rectangular opening into which a chute-door was fit, with a hinged drop panel. The hinged panel was propped up by a stick, which was knocked down when the pig entered the trap. At King Ranch we used triangular-shaped panel traps, which had a similar trap door mechanism as those traps used at WWF. Traps were baited and set at dusk; they were checked at dawn to prevent captured pigs from overheating.

At Chaparosa and King Ranches, captured pigs were transported with a trailer and shot in the head by a skilled marksman with a .22 caliber pistol at the necropsy laboratory. At WWF, a trailer was not available, and the pigs were shot within the trap before transport to the necropsy laboratory.

After the pig was shot, blood was collected immediately from the vena cava. Two 7-ml glass tubes (Vacutainer, Fisher Scientific Co., Santa Clara, California, USA) coated with potassium ethylenediaminetetra-acetic acid ($K_3$-EDTA) were used to collect blood for whole blood analysis. Two 13-ml glass tubes were used to collect blood for serum analysis. Blood was kept on crushed ice until returned to the laboratory (within 2 hr). At the laboratory, blood was centrifuged to obtain serum and two blood smears were prepared from each of the $K_3$-EDTA whole blood samples.

Smears, serum, and whole blood samples

were sent to the Texas Veterinary Medical Diagnostic Laboratory, College Station, Texas, via overnight express cold-pack service. In order to determine laboratory accuracy, six blind samples were prepared; samples from six pigs were divided in half and sent to the lab under separate numbers to ensure consistent testing. Laboratory serum assays were conducted with a Hitachi 911 machine (Boehringer-Mannheim Co, Indianapolis, Indiana, USA); hematologic assays were conducted with a Cell-Dyne 3500 (Abbot Diagnostics, Abbott Park, Illinois, USA) and by manual differentiation.

Each pig was searched for 5 min for ectoparasites; 2.5 min each were allocated to the anterior (ears, head, and neck) and posterior (groin, tail, and haunches) regions of the pig, respectively. Pigs were aged according to Matchke's (1967) dentition formula, which provided ages corresponding to tooth eruption patterns from birth to 26 mo. The upper first premolars from pigs with a full set of adult teeth were aged by cementum layers (Matson's Laboratory, Milltown, Montana, USA). Because domestic pigs reach sexual maturity at an average age of 200 days (Pond and Houpt 1978), pigs classified by Matson's Laboratory as 20–33 wk old or below were considered juveniles and pigs classified as 30–51 wk old or above were considered adults.

The liver, kidneys, lungs, esophagus, stomach, small intestine, and colon of each pig were evaluated for parasites (Shender, 1998). The liver was carefully sliced and checked for signs of necrosis or scar tissue from migrating parasites, as well as for black hematin pigment characteristic of liver flukes (Foreyt et al., 1975). Intestinal contents were passed through sieves with mesh sizes of 1.9, 0.72, and 0.14 mm, respectively, and were checked for parasites.

All parasites were preserved in 70% ethyl alcohol with 5% glycerin. Ticks were identified to species (U.S. Department of Agriculture, 1976) and type specimens (RML Numbers 122478 through 122491) were deposited in the U.S. National Tick Collection (Statesboro, Georgia, USA). Voucher specimens of all helminths were identified at and deposited in the U.S. National Parasite Collection (USNPC Numbers 87257 through 87263 and 87328 through 87331) (Beltsville, Maryland, USA). Terms used to describe parasitic presence follow Margolis et al. (1982). For statistical analyses, all lungworms were grouped as *Metastrongylus* spp.

All statistical analyses were calculated using Number Cruncher Statistical Systems 6.0 (Kaysville, Utah, USA). We used a significance level of alpha = 0.05 for all analyses. Univariate analyses were used to test for differences between sexes and ages, whereas all relationships between parasites and serum or whole blood variables were assessed with multivariate analyses only.

Parasite numbers were tested for normality and, when not normally distributed, were transformed using log $(y + 1)$, where y = the original parasite number. For cases in which logarithmic transformations still did not meet normality, no further transformations were made and all outliers were retained. A Pearson correlation was used to compare estimated age categories of pigs (in weeks) and the logarithmic transformations of the numbers of ticks, kidney worms, and lungworms as well as the total number of liver flukes. Paired *t*-tests were used to evaluate any discrepancies in blood parameters of six blind samples. We compared parasite prevalences between adult and juvenile pigs using a Chi-square test. A Kolmogorov-Smirnov test was used for non-normal and heteroscedastic data to test for differences in mean intensities between adult and juvenile pigs.

Means and standard deviations for 33 serum and whole blood variables were calculated by sex, by age, and for total pigs. Each variable was tested to determine if there were significant differences between the means of ages or sexes. If the data were normally distributed and homoscedastic, an equal variance *t*-test was used. If the data were normally distributed and heteroscedastic, an unequal variance *t*-test was used. If the data were not normally distributed and homoscedastic, a Mann-Whitney *U*-test was used. If the data were not normally distributed and heteroscedastic, a Kolmogorov-Smirnov test was used.

The large number of blood variables collected posed a problem for our analysis of the relationship between blood variables and parasite levels for two reasons. First, the potential number of correlations between all of the independent (serum and whole blood) and dependent (parasite) variables was very large, leading to the risk of a large number of significant correlations due to chance alone. Second, the selection procedures and statistical power of multiple regression analyses are compromised when the number ratio of sample size to independent variables is below five. To reduce these problems, we ran a Bartlett's sphericity test and conducted a principal component analysis (PCA) on the serum and whole blood variables to reduce them to a smaller number of PCA factors that explained most of the variables in the original data set. For clusters of highly correlated variables ($r > 0.75$), we examined the data and eliminated all but one variable. Omitted serum variables consisted of lactic dehydrogenase,

globulin, globulin/albumin ratio, and chloride. The whole blood variables omitted were total number of WBC, red blood cells (RBC), PCV, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and plasma protein/fibrinogen ratio. Only those principal component (PC) factors with eigenvalues >1 were included; this accounted for at least 61% of the total variation. The variables associated with each factor were determined by a factor loading threshold value, which was set by sample size (Stevens, 1996). We omitted coagulated whole blood samples and hemolyzed serum samples to reduce false readings for blood variables. To minimize the effects of missing values, separate PCAs were calculated for the serum and whole blood variables.

Multiple regression analysis was used to obtain the partial correlation coefficients between PC factors and logarithmic transformations of the number of kidney worms, lungworms, and ticks as well as to determine which correlations were significant. Due to low prevalence and intensities, multiple regression analyses were not run on *F. magna, Oesophagostomum dentatum,* and *Physocephalus sexalatus.* Separate multiple regression analyses were evaluated for juvenile and adult pigs in order to reduce biases caused by age-related parasite infections.

Logistic regression analyses were used to evaluate relationships between parasite prevalences and serum and whole blood PC factors. Tick prevalence was excluded from this analysis because ticks occurred on all but one pig.

## RESULTS

During the summers of 1996 and 1997, 36 pigs were collected and necropsied from WWF, 14 from Chaparosa Ranch, and 10 from King Ranch. We found 10 parasite species: five nematodes, one trematode, and four ixodid ticks (Table 1). Among nematodes, *Stephanurus dentatus* was found in the kidneys; *Oesophagostomum dentatum* occurred in the large intestine, and *Physocephalus sexalatus* was found in the stomach. Among lungworms we found both *Metastrongylus salmi* and *Metastrongylus pudentotectus* but combined these two species for all statistical analyses. The trematode *Fascioloides magna* occurred in the liver. Prevalences and intensities of some parasites were significantly different between adult and juvenile pigs (Table 1). Age estimates (in weeks) were positively correlated to liver fluke numbers ($r = 0.27$; $P = 0.036$) and the log number of kidney worms ($r = 0.59$; $P < 0.01$).

Serum and whole blood were obtained from 60 pigs (Table 2). There was no significant difference between the means of the serum and whole blood parameters of the six paired blind samples ($P > 0.05$ for all comparisons). Among all variables, only MCH and RBC differed between all males and all females. Mean (±SD) MCH was significantly ($P = 0.035$) lower in males (18.5% ± 1.8) than in females (19.6% ± 1.6). Mean (±SD) RBC number was significantly ($P = 0.047$) higher among males ($6.60 \pm 0.94 \times 10^6/mm^3$) than females ($5.93 \pm 1.13 \times 10^6/mm^3$). In contrast, there were more differences among serum and whole blood variables between adult and juvenile pigs (Table 2).

Based on Bartlett's sphericity test, we rejected the null hypothesis that the correlation matrix was an identity matrix and that all correlations were zero ($P < 0.01$); we thus proceeded with a PC analysis. After eliminating 18 hemolyzed serum samples from field-shot pigs, the PC analysis was conducted on the remaining 42 serum samples. Serum variables were reduced to three principal components, which together accounted for 52% of the total variation (Table 3). Principal component 1 was positively correlated with AP; PC-2 was positively correlated with both alanine aminotransferase and aspartate aminotransferase; and PC-3 was positively correlated with both calcium and bilirubin. The sample size of juvenile pigs ($n = 13$) was too small to run a multiple regression analysis against the three serum PC factors and confidently present results.

After eliminating 12 blood samples with coagulation, the remaining 48 samples were used for whole blood analysis. Principal components analysis resulted in three factors, which accounted for 65% of total variation (Table 3). Principal component 1 was positively correlated with lymphocytes and eosinophils, PC-2 was negatively cor-

TABLE 1. Prevalences and mean intensities of parasites in 60 adult (30–51 wk) and juvenile (<20–33) wild pigs (*Sus scrofa*) at three sites in Texas, USA; June through August, 1996 and 1997.

| Parasite | Prevalence (%) | | | Intensity | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Adult ($n$ = 36) | | Juvenile ($n$ = 24) | | Total ($n$ = 60) |
| | Adult $n$ = 36 | Juvenile $n$ = 24 | Total $n$ = 60 | Mean (SD) | Range | Mean (SD) | Range | Mean (SD) |
| Nematodes | | | | | | | | |
| *Stephanurus dentatus* | 41[a] | 0 | 25 | 15.2 (12.3) | 1–41 | NA[b] | 0 | 15.2 (12.3) |
| *Metastrongylus* spp.[c] | 70 | 74 | 72 | 56.5 (58.7) | 1–197 | 377 (586)[d] | 1–2,230 | 183.1 (397.6) |
| *Oesophagostomum dentatum* | 8 | 0 | 5 | 15.0 (13.1) | 1–29 | NA | 0 | 15.0 (13.1) |
| *Physocephalus sexalatus* | 14 | 0 | 8 | 16.0 (19.2) | 1–48 | NA | 0 | 16.0 (19.2) |
| Trematodes | | | | | | | | |
| *Fascioloides magna* | 19[e] | 0 | 13 | 1.4 (1.1) | 1–4 | NA | 0 | 1.4 (1.1) |
| Ticks | | | | | | | | |
| *Amblyomma cajennense* | 97 | 96 | 97 | 16.0 (17.6) | 1–94 | 19.4 (18.4) | 1–70 | 17.4 (17.8) |
| *Amblyomma maculatum* | 47 | 30 | 40 | 4.8 (4.4) | 1–16 | 1.7 (1.1) | 1–4 | 3.9 (3.9) |
| *Amblyomma americanum* | 6 | 0 | 3 | 1.5 (0.7) | 1–2 | NA | 0 | 1.5 (0.7) |
| *Dermacentor variabilis* | 19 | 35 | 25 | 3.0 (2.1) | 1–7 | 14.9 (9.0)[e] | 1–25 | 10.1 (9.2) |
| All Ixodidae[f] | 100 | 96 | 98 | 19.5 (18.5) | 1–101 | 25.6 (17.0)[e] | 3–80 | 21.5 (18.0) |

[a] Prevalence significantly ($P \leq 0.01$) higher in adults than in juveniles.
[b] NA: No juveniles were infected.
[c] *Metastrongylus salmi* and *Metastrongylus pudentotectus* combined for analyses.
[d] Mean intensity significantly ($P \leq 0.05$) higher in juveniles than in adults.
[e] Prevalence significantly ($P \leq 0.05$) higher in adults than in juveniles.
[f] Total ticks including unidentified nymphs.

related with mature neutrophils and monocytes, and PC-3 was positively correlated with fibrinogen.

The log number of ticks among juveniles was negatively correlated with whole blood PC-1 (lymphocytes and eosinophils; $r^2$ adjusted = 44%, $P = 0.0056$; Table 4). The log number of lungworms among adults was negatively correlated with whole blood PC-2 (mature neutrophils and monocytes; $r^2$ adjusted = 24%, $P = 0.0076$). This negative correlation with PC-2 indicates a positive correlation between lungworm numbers and both neutrophils and monocytes because these variables were negatively associated with PC-2. There were no significant correlations between parasite prevalence and PC variables.

## DISCUSSION

All ten parasite species identified have been reported previously in feral pigs. Humbert (1991) calculated a lungworm infection mean intensity of 167 parasites per infected pig; we found a comparable value of 183 (Table 1). Humbert (1991) noted a large range of three to 1,602 lungworms/lung; this is similar to the range of two to 2,230 worms/two lungs that we report.

Prevalence of lungworms was similar among both adults and juveniles (Table 1) but the log number of lungworms was negatively correlated with age. Humbert (1991) also found that pigs less than 1 yr old had a greater intensity of infection than did older pigs and suggested two reasons to explain this age-dependent correlation: younger pigs eat larger amounts of animal matter than older pigs and are therefore more prone to infection from consumption of earthworm intermediate hosts, and acquired immunity is established only after a several contacts with the parasite.

Although we found no previous reports of kidney worm prevalences being lower in juveniles, the relationship seems reasonable because the life cycle of *Stephanurus dentatus* requires approximately 6 mo (Soulsby, 1965), and therefore pigs under 6 mo will not have mature parasites in their kidneys. However, this explanation does not fully account for a correlation between age and log number of parasites.

We did not expect to find so few liver flukes. Foreyt et al. (1975) found a liver fluke prevalence of 74% on the WWF. This is a sharp contrast to the observed prevalence of 13% in our study. In addition, all ages of pigs examined by Foreyt et al. (1975) were infected, whereas we found no pigs younger than 30 wk infected with flukes. Drought conditions during our study may have been a contributing factor to the lower liver fluke prevalence observed (Shender, 1998).

Pigs first transported to the necropsy lab in the trailer at the Chaparosa and King ranches may have become more stressed than pigs immediately shot in the trap at WWF. Thus some sensitive blood values may have become affected. For example, elevations of Hb, PCV, and RBC often occur with physical exertion resulting from hemoconcentration (DelGiudice et al., 1990). However, due to small sample sizes and an uneven distribution of ages between study sites, we could not statistically analyze data for possible differences in blood values attributed to these treatment effects.

The finding of few significant differences in biochemical values between sexes was consistent with previous studies. Williamson and Pelton (1975) found no significant differences between sexes for 11 serum values tested. We found significant differences only for RBC and MCH.

Williamson and Pelton (1975) found significant differences between juveniles (<10 mo) and adults (≥10 mo) for chloride, total serum protein (TSP), globulin, albumin, and sodium levels. We also found significant differences between juveniles (20–33 wk and below) and adults (30–51 wk and above) for chloride, TSP, and globulin but not for albumin or sodium (Table 2).

The log number of ticks among juvenile

TABLE 2. Comparison of serum and whole blood parameters between juvenile and adult wild pigs (*Sus scrofa*) from three sites in Texas, USA; June through August, 1996 and 1997.

| Variable | Number | Mean (SD) | Range | Adults[a] (>30–51 wk) Mean (+SD) | Juveniles[b] (<20–33 wk) Mean (± SD) | Juvenile vs. adult P-value (test used[c]) |
|---|---|---|---|---|---|---|
| *Serum* | | | | | | |
| Total serum protein (mg/dl) | 60 | 7.78 (1.45) | 5.60–11.30 | 8.36 (1.42) | 3.65 (0.70) | 0.0002 (1) |
| Albumin (mg/dl) | 60 | 3.63 (0.59) | 2.60–5.60 | 3.62 (0.51) | 3.65 (0.70) | NS[d] |
| Globulin (mg/dl) | 60 | 4.15 (1.54) | 2.00–7.90 | 4.75 (1.51) | 3.26 (1.09) | 0.0001 (2) |
| Albumin/globulin ratio (1:) | 45 | 0.94 (0.40) | 0.40–2.10 | 0.88 (0.35) | 1.08 (0.50) | NS |
| Glucose (mg/dl) | 60 | 147.7 (73.6) | 2.0–359.0 | 138.4 (67.6) | 161.6 (81.3) | NS |
| Serum urea nitrogen (mg/dl) | 60 | 15.0 (5.2) | 6.0–30.0 | 15.1 (4.2) | 14.9 (6.5) | NS |
| Creatinine (mg/dl) | 60 | 1.34 (0.43) | 0.60–2.30 | 1.56 (0.41) | 1.00 (0.17) | <0.00001 (3) |
| Bilirubin (mg/dl) | 60 | 0.20 (0.15) | 0.04–1.10 | 0.16 (0.07) | 0.22 (0.11) | NS |
| Alkaline phosphatase (IU/l) | 60 | 104.0 (67) | 20.0–293.0 | 71.5 (46.5) | 152.8 (63.9) | <0.00001 (4) |
| Creatinine phosphokinase (IU/l) | 45 | 2,740 (3,430) | 311–16,700 | 2,706 (3,332) | 2,828 (3,791) | NS |
| Lactic dehydrogenase (IU/l) | 45 | 976 (1,710) | 286–12,000 | 1,020 (2,030) | 867 (318) | 0.022 (1) |
| Alanine aminotransferase (IU/l) | 45 | 41.9 (26.8) | 7.0–161.0 | 47.2 (28.1) | 28.8 (18.1) | 0.014 (4) |
| Aspartate aminotransferase (IU/l) | 45 | 113.4 (172.4) | 29.0–1,140 | 124.2 (200.9) | 86.8 (60.1) | NS |
| Calcium (mg/dl) | 60 | 10.01 (0.89) | 8.30–13.30 | 9.89 (0.74) | 10.19 (1.06) | NS |
| Phosphorus (mg/dl) | 60 | 7.33 (1.79) | 4.20–12.60 | 6.90 (1.76) | 7.96 (1.67) | 0.0071 (4) |
| Sodium (meq/l) | 56 | 145.8 (5.2) | 137.2–159.0 | 145.1 (5.0) | 146.7 (5.6) | NS |
| Chloride (meq/l) | 56 | 103.6 (4.8) | 94.0–113.0 | 102.6 (4.7) | 105.2 (4.7) | 0.043 (2) |
| Gamma-glutamyl transferase (IU/l) | 45 | 35.3 (10.8) | 17.0–73.0 | 34.4 (10.9) | 37.7 (10.8) | NS |
| *Blood cells* | | | | | | |
| Red blood cells ($10^6$/mm$^3$) | 52 | 6.28 (1.08) | 2.20–9.20 | 6.02 (0.76) | 6.70 (1.38) | 0.0078 (1) |
| Hemoglobin (HB) (g/100ml) | 52 | 11.96 (1.64) | 4.10–14.60 | 12.03 (1.25) | 11.85 (2.16) | NS |
| Packed cell volume (%) | 52 | 37.7 (5.2) | 13.4–46.0 | 37.86 (3.85) | 37.38 (6.85) | NS |
| Mean corpuscular volume ($u^3$) | 52 | 63.4 (6.5) | 36.0–79.0 | 65.5 (4.2) | 60.05 (8.11) | 0.0005 (1) |
| Mean corpuscular HB concentration (%) | 52 | 31.2 (2.5) | 22.6–35.2 | 31.3 (2.2) | 31.0 (3.0) | NS |
| Mean corpuscular HB (pg) | 52 | 19.0 (1.8) | 14.8–22.8 | 19.9 (1.5) | 17.7 (1.3) | 0.00001 (4) |
| Total white blood cells (number/mm$^3$) | 52 | 15,700 (8,060) | 2,400–40,200 | 13,566 (6,778) | 18,845 (8,865) | 0.015 (2) |
| Band neutrophils (number/mm$^3$) | 52 | 134 (310) | 0–1980 | 116 (359) | 162 (221) | NS |
| Segmented neutrophils (number/mm$^3$) | 52 | 8,440 (6,510) | 335–30,500 | 8,087 (5,609) | 8,958 (7,770) | NS |
| Lymphocytes (number/mm$^3$) | 52 | 5,980 (3,790) | 1,680–16,600 | 4,532 (2,340) | 8,112 (4,525) | 0.0043 (1) |

TABLE 2. Continued.

| Variable | Number | Mean (SD) | Range | Adults[a] (>30–51 wk) Mean (+SD) | Juveniles[b] (<20–33 wk) Mean (± SD) | Juvenile vs. adult P-value (test used[c]) |
|---|---|---|---|---|---|---|
| Monocytes (number/mm$^3$) | 52 | 570 (645) | 0–4,020 | 445 (422) | 75 (856) | NS |
| Eosinophils (number/mm$^3$) | 52 | 391 (735) | 0–4,220 | 308 (505) | 512 (985) | NS |
| Fibrinogen (F) (mg/dl) | 49 | 255 (160) | 100–800 | 254 (155) | 256 (172) | NS |
| Total plama protein (PP) (g/dl) | 49 | 8.39 (1.28) | 6.40–11.60 | 8.81 (1.20) | 7.65 (1.10) | 0.0016 (2) |
| PP/F | 46 | 42.93 (24.83) | 7.40–99.00 | 43.64 (26.6) | 41.83 (22.5) | NS |

[a] $n$ = 28–36.
[b] $n$ = 13–24.
[c] Test used: 1 = Kolmogorov-smirnov test, 2 = equal variance $t$-test, 3 = unequal variance $t$-test, 4 = Mann-Whitney $U$-test.
[d] Not significant.

pigs was negatively correlated with whole blood PC-1; this PC factor was associated with lymphocytes and eosinophils. This relationship appeared to be driven by two outliers that represented pigs with zero and three ticks, respectively; when these two outlier values were removed, the relationship was no longer significant ($P$ = 0.17). The log number of lungworms among adult pigs was negatively correlated with whole blood PC-2. This PC factor was negatively associated with mature neutrophils and monocytes; therefore this negative correlation was actually a positive correlation between lungworm numbers and neutrophils/monocytes. It was surprising not to find a similar relation among juvenile pigs, especially since they had a much wider range of lungworms (0–2,230) than did adults (0–197). Wolkers et al. (1994a) stated that increasing numbers of *Metastrongylus* spp. generally result in an increase of total leukocytes; however, due to its high correlation to individual leukocyte variables, total leukocyte counts were omitted from our PC analysis. As was the case for Wolkers et al. (1994a), we did not find an increase in eosinophils in response to increasing lungworm intensities. Perhaps the stimulus for eosinophilia may be developing or molting larvae; within 1 wk following a peak in eosinophils, which occurs 2 wk after infection, levels return to normal values (Wolkers et al., 1994a).

## MANAGEMENT IMPLICATIONS

Despite several exceptions, the null hypothesis that blood parameters did not vary significantly with parasite prevalence and intensity generally was not rejected. Overall, the applicability of using blood values as predictors of parasite presence in individual animals does not seem practical for at least two reasons. Most significant correlations with parasites were weak; also the possible confounding effects of other factors such as nutrition, stress, and age could not be clearly separated in our study. Thus we do not recommend serum or whole blood parameters as likely indicators

TABLE 3. Principal component (PC) factors based on serum and blood cell variable from wild pigs (*Sus scrofa*) at three sites in Texas, USA, June through August, 1996 and 1997.

| Analysis | Eigenvalue | | | |
|---|---|---|---|---|
| | Principal components | Percent variation | Factor loading | Variables[a] |
| Serum[b] | PC-1 | 21 | +0.85 | +Alkaline phosphatase |
| ($n$ = 42) | PC-2 | 16 | +0.85 | +Alanine aminotransferase |
| | | | +0.82 | +Aspartate aminotransferase |
| | PC-3 | 15 | +0.81 | +Calcium |
| | | | +0.83 | +Bilirubin |
| | Total | 52 | | |
| Blood cells[c] | PC-1 | 26 | +0.80 | +Lymphocytes |
| ($n$ = 48) | | | +0.80 | +Eosinophils |
| | PC-2 | 23 | −0.92 | −Mature neutrophils |
| | | | −0.87 | −Monocytes |
| | PC-3 | 16 | +0.79 | +Fibrinogen |
| | Total | 65 | | |

[a] Positive and negative signs preceding variables indicate their orientation on PC axis.
[b] Variables with factor loading >0.785 were considered important factors in each component.
[c] Variables with factor loading >0.736 were considered important factors in each component.

of parasite prevalence or intensity among individual animals at this time.

Although the types of analyses conducted in this study were not useful for establishing a clear relationship between parasite loads and blood or serum values among individual animals, it may be possible to use serum and whole blood values to make inferences about differences in parasite loads between populations. Correlations found in this study between parasite loads and blood values might be useful to detect differences in parasite loads among different populations if adequate sample sizes were available.

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TABLE 4. Partial correlation coefficients for serum and whole blood principal component factors and log number of parasites of juvenile (≤20–33 wk) and adult (≥30–51 wk) wild pigs (*Sus scrofa*) from three sites in Texas, USA, June through August, 1996 and 1997.

| Principal component (PC) | Juveniles | | Adults | | |
|---|---|---|---|---|---|
| | Lungworms | Total ticks | Lungworms | Kidney worms | Total ticks |
| Serum ($n_1$ = 13 juveniles; $n_2$ = 29 adults) | | | | | |
| PC-1: +Alkaline phosphatase[a] | ND[b] | ND | −0.073 | −0.36 | 0.15 |
| PC-2: +Alanine aminotransferase +Aspartate aminotransferase | ND | ND | 0.22 | 0.018 | 0.35 |
| PC-3: +Calcium, +bilirubin | ND | ND | 0.22 | −0.15 | 0.079 |
| Whole blood ($n_3$ = 18 juveniles; $n_4$ = 30 adults) | | | | | |
| PC-1: +Lymphocytes, +eosinophils | 0.43 | −0.66[c] | −0.080 | 0.13 | 0.38 |
| PC-2: −Segmented neutrophils, −monocytes | 0.072 | −0.34 | −0.49[c] | 0.30 | −0.21 |
| PC-3: Fibrinogen | −0.21 | −0.13 | −0.11 | −0.21 | −0.11 |

[a] The negative and positive signs preceding each variable denote their orientation on the PC axis.
[b] ND: not done. Because of the small sample size ($n$ = 13) of juvenile pigs for which serum samples were available, a multiple regression analysis was not conducted for serum values.
[c] Significant at $P < 0.01$.

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